GIS Analysis of Unglaciated Allegheny Plateau Bedrock as an Abiotic Component Impacting Regional Forest Type

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By

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Table of Contents

Acknowledgments

I would like to take this opportunity to thank those without whose help this project would not have been possible: Dr. Lyons, for taking me under your wing as an advisee and encouraging me to find a project which would be of personal interest; Brian Riley, for dealing with my incessant questions regarding forest ecology and recommending the literature in which to find answers; Anastasiya Levin and Lisa Schaller, for grammatical assistance; and to Dean Martin, Jeff Lewis, Cotton Randall and Bob Parkinson for your assistance with GIS layers and analysis.

Abstract

Forest type and growth patterns, specifically species growth preferences, are correlated. Extensive literature review has revealed that natural (growth before pioneer disturbance) forest habitats are characterized by the climate and topographic conditions where a forest has been growing. However, with regards to bedrock, the literature only commits on the soil type, calcareous or other; very little detail outside of this characteristic is mentioned. GIS analysis enables the knowledge of numerous fields - including climatology, geography, ecology and geology - to be combined in this investigation. Specifically, GIS enables the removal of known limiting abiotic (non-living) components - precipitation, elevation, aspect and the number of frost-free days per year - to discern if different forest types have preferred bedrock types. The study area, southeastern Ohio, was selected due to its lack of glacial till, acting as a buffer between bedrock and the forest growth above it. At the scale of this study, this analysis increases the knowledge of forest habitats and their direct relationship to bedrock type.

List of Figures

Introduction

Abiotic factors surrounding forest development and succession are an integral part of a forest ecosystem. Characteristics such as light, soil type and precipitation have been studied and recorded by foresters for decades. One parameter which has received limited attention is the geology - or bedrock - underneath the forests. Multiple physical and chemical characteristics of the underlying bedrock comprise the habitats that many tree species desire; these include pH, affinity for erosion, and ability to store water.

The challenge manifest in correlating a specific forest type with bedrock type is the exclusion of the impact of other parameters that define a suitable forest habitat: shade, precipitation, slope aspect and general climate conditions. The approach taken to date for acquiring these parameters is to record the specific location of a forest type and the environmental conditions surrounding it. The result of this approach is observational data that ignores bedrock as a determining factor for forest habitat.

This study uses a computer-generated analysis called Geographic Information System (GIS) to isolate the preferred habitats of each natural forest type found in the unglaciated Allegheny Plateau in southeastern Ohio. Using shapefiles that contain attributes pertaining to habitat characteristics provided by state and federal organizations, the GIS program helps isolate areas that meet the preferred habitat characteristics of a particular forest. Once the area is isolated, an analysis of preferred bedrock types can be conducted by evaluating the percentage of a specific forest type covering each type of bedrock.

Study Area

The Ohio landscape has been compressed, scoured and blanketed by glaciers at least four times in the last two million years. The most recent of these glacial events reached its zenith approximately 18,000 years ago. The result of these glaciers was a significant change in the overall landscape of Ohio. Today, there is 6-221 meters of glacial till covering the majority of the state and creating a buffer between the bedrock and the forests growing at the surface (Ohio DNR drift thickness map). Due to the uplift caused by the Allegheny Orogeny and the resistive nature of the bedrock affected, southeastern Ohio received very little glacial till. This lack of glacial till separating the bedrock from the surface in the unglaciated Allegheny Plateau creates the ideal location to study the effects of bedrock type on forest type.

Geology

Seven generalized geologic bedrock types are found in the unglaciated Allegheny Plateau, based on the Ohio Geologic Bedrock shapefile provided by the Ohio Environmental Protection Agency (Figure 2). These bedrock types were formed during the Palezoic era, starting in the Silurian period (400 million years ago) and through the Permian period (200 million years ago). They include black shale, shale, dolostone, sandstone, limestone, mudstone and siltstone.

Black Shale

Black shale is from the Upper Devonian period (385-360 ma). Like other shales, black shale is a mudrock composed of clay sized clastic sediment. It differs from other shale due to the presence of a greater than one percent carbonaceous material which provides its rich black or dark brown color. Some black shale is arenaceous in composition. Physically, black shale splits easily into slate-like slabs or pieces (Lamborn 1951).

Shale

Shale bedrock stems from the Silurian to the Pennsylvanian periods (445-300 ma). In composition, shale is described as arenaceous, siliceous, ferruginous and sandy with limestone and pyrite impurities in part. Shale is a mudstone which consists of clay sized clastic material. This bedrock varies in color, including hues of blue, blue-gray, gray, black, brown and reddish brown. When exposed to weathering, shale tends to crumble easily and break into thin layers (Lamborn 1951).

Siltstone

Formed during the Pennsylvanian period (445-460 ma), siltstone is characterized by the majority of silt-sized clastic grains that form its structure. This rock ranges in color from blue, blue-gray and gray to black, red and reddish brown. Siltstone is siliceous, sandy and ferruginous. It is compact, and rarely affected by weathering (Lamborn 1951).

Dolostone (Dolomite)

Dolomite bedrock in the unglaciated Allegheny Plateau was formed during the Silurian period (445-415ma). Pure in composition, dolomite rarely appears with other minerals or substances. Its surface varies in color, running the gamut from white or gray to blue or brown. Physically, dolomite has been characterized by field geologists as compact, tough and rarely affected by weathering. However, some dolomite is described as porous when weathered, resulting in a pronounced honeycomb effect (Stout 1941).

Sandstone

Sandstone bedrock of the Allegheny Plateau was formed during the Mississippian period (360-320 ma). Its composition is primarily quartz, with trace amounts of aluminum, iron and calcium carbonate bearing compounds. Sandstone's color varies from blue-gray to gray. This bedrock is fine- to medium-grained, heavy bedded and well cemented (Lamborn 1951).

Limestone

Formed during the Silurian period (445-415), limestone ranges in color from very light gray/white, gray or buff to pink or brownish red. In composition, limestone contains a high percent of calcium carbonate and a low percent of siliceous or ferruginous impurities. It also has the capacity to vary from soft and porous to hard and dense.

Mudstone

Ohio Mudstone is identified as originating during the Pennsylvanian and the Permian periods (320-250 ma). Much like shale, mudstone is consists mostly of clastic clay sized particles. It is siliceous, and can be sandy or ferruginous in part. Colors for mudstone are similar to those of siltstone: gray, blue-gray, brown and red hues. Its physical characteristics are similar to those of shale, though mudstone is not typically fissile (Lamborn 1951).

Forest Ecology

Eight general forest types represent the natural forests of the unglaciated Allegheny Plateau in Ohio. These forests were identified from a shapefile based on a digitized version of Robert Gordon's map, entitled "The Natural Forest of Ohio in Pioneer Days" (1969); this map is an approximated compilation of data based on early land surveys (Figure 3). Many of these forest types consist of multiple species of trees, each with its own preferred habitat characteristics. For the sake of simplicity, the characteristics used to define the preferred forest habitat were comprised of the more rigid abiotic habitat characteristics of each species of tree found in that forest.

Beech Forests

The Beech forest type consists primarily of American Beech trees. This species is found in the eastern half of the United States and tends to prefer cooler, moister northern slopes to dryer southern slopes. American Beech trees grow best in coarse, dry, mesic (moderately moist) soils with a pH of 4.1-6.0 and are very tolerant of shade. Beech forests require 76-127 cm of precipitation and 100-280 frost-free days a year.

Mixed Oak Forests

This system is present in the majority of the eastern United States, with its northern limit just above the southern border of Michigan. Tree species for this forest type includes white oak, scarlet oak, pin oak, chestnut oak, northern red oak and black oak. Mixed oak forests prefer cool, moist northerly and easterly aspects, with mild to moderate slopes and well-drained soil types. This forest requires 76-203 cm of precipitation and 140-220 yearly frost-free days.

Oak-Sugar Maple Forests

A system indigenous to the eastern United States, oak-sugar maple forests range from their northern limit of central Michigan to a southern limit at the Tennessee-Georgia border. This system is best represented by northern red oak, black oak and sugar maple, and it is moderately tolerant of shade. Trees in this forest system also prefer cool, moist northerly and easterly aspects, along with mild to moderate slopes and well-drained soils. Oak-sugar maple forests require 76-203 cm of precipitation, and 140-220 frost-free days per year.

Prairie Grassland Forests

Prairie grassland forests grow in the central part of the country, with a northern limit just above Wisconsin and a southern limit in central Texas. The major tree type of this system is the bur oak. This species prefers calcareous soil types and can live on sites with thin soils. It is often found along prairie edges, where it meets upland forests. Bur oak is drought-resistant, only requiring 38-127 cm of precipitation and 100-260 frost free days per year.

Freshwater Marshes and Fens

The Freshwater Marshes and Fens system is predominately made up of pussy willows, black willows, sandbar willows and buttonbush. These species are found in the eastern United States, growing on almost any soil type. However, due to shallow roots, these species require an abundant continuous supply of moisture, and therefore are found on the rims of water systems (i.e. rivers, swamps, sloughs), at or just below the water level. Although the majority of its moisture is obtained via local water systems, freshwater marshes and fens require an average of 130 cm of precipitation per year and are very intolerant of shade. No requisite number of annual frost-free days was noted; nonetheless, this forest is said to be very resilient to extreme temperatures, ranging from 46^{o} to -49^{o} C.

Bottomland Hardwood Forests

This forest type consists of the most varied tree types, including black walnut, sycamore, silver maple, cottonwood, hackberry, shellbark hickory, Ohio buckeye, box-elder, green ash, American elm, hackberry and honeylocust. Bottomland Hardwood forests can generally be found in the northeastern part of the United States, growing in or around streams. Its general soil type is characterized as well-drained, with a pH of 5.5-7.5. This forest type requires 81-152 cm of precipitation and 120-160 frost-free days per year.

Elm-Ash Swamp Forests

The Elm-Ash forest consists of green ash and American elm trees. These species are found in the eastern half of the United States, but they are very adaptive to multiple habitats. Their preferred soil types range from clayey soils subject to flooding to well-drained sandy soils with a pH range of 5.5-8.0. They can be found mostly in bottomlands but also grow well on moist upland soils. These trees require 38-152 cm of precipitation and 120-160 frost-free days a year. Elm-Ash forests also grow best in full sunlight, but are tolerant of shade.

Mixed Mesophytic Forests

This system can be found in the plains and hill country, bounded on the west by the Allegheny Mountains and on the north by southwestern Pennsylvania. Mixed Mesophytic forests' tree types include yellow buckeye, American basswood, oaks, hickories and walnuts. This tree system grows in river bottoms in mesic soils and requires 99-114 cm of precipitation and 150-210 annual frost-free days. Trees in this system thrive in soils with pH levels of 4.5-7.5 but are said to prefer slightly basic calcareous soils. Mixed Mesophytic forests are shade-tolerant and are said to grow best on northern-facing slopes.

Methods

In order to accurately associate forest type with a preferred bedrock type, a simple ratio assessing percentage of total acre coverage over each bedrock type must be established. However, in order to eliminate other acting variables, the preferred above-surface habitat based on abiotic components must first be considered and isolated through GIS analysis. Such variables include hydrology, proximity to a known water source; climatology, amount of precipitation and number of annual frost-free days; and aspect, the cardinal slope direction of a hillside. Once isolation of the preferred variables has taken place, a simple statistical computation of total acreage of the ideal habitat can be performed through the attribute table of the shapefile. This will indicate the total acreage on which a particular forest can be found over each bedrock type within the parameters of the preferred habitat.

All of the data used in this analysis are vector shapefiles in the form of polygons. All layers are expressed using a NAD_1983_StatePlane_Ohio_South_FIPS_3402_Feet coordinate system with a Lambert_Conformal_Conic projection.

Hydrology

The hydrology GIS layer was obtained from the Ohio Department of Natural Resources GIMS Data search. It contains polygons for streams, wetlands, marshes, bogs, dams, reservoirs, lakes, ditches and canals - both intermittent and constant flow. It also contains polygons labeled unclassified, representing areas not classified as hydrologic bodies. For the simplicity of the analysis, these polygons were grouped into three categories: dry (unclassified), intermittent flow and constant flow (Figure 4).

Climatology

The shapefile dealing with precipitation was obtained from the Geospatial Data Gateway through the United States Department of Agriculture. It displays contour lines of annual precipitation amounts ranging from 94-114 cm per year (Figure 5). The frost data was derived from a photomap showing the approximated number of frost-free days per year at the county level (Figure 6). In order to apply this parameter to the analysis, the Ohio county shapefile was utilized (Figure 7).

Aspect

Aspect was calculated using the aspect tool in the surface category of the spatial analysis tools. This tool utilizes the data from a Digital Elevation Model (DEM), which was obtained from the Ohio Department of Natural Resources. Each cell in the DEM is evaluated using an algorithm which looks at the eight cells surrounding it. The rise-versus-run of each cell is obtained and then calculated using: aspect = 57.29578 * atan2 ([dz/dy], -[dz/dx]) where (dz/dy) = ((g + 2h + i) - (a

+ 2b + c)) / 8 and (dz/dx) = ((c + 2f + i) - (a + 2d + g)) / 8. The aspect is then given an angle of direction where 0^{o} is due north and subsequent angles increase moving clockwise (90^{o} is due east). An illustration and an explanation of other terms can be found at http://resources.esri.com/help/9.3/ArcGISDesktop/dotnet/Gp_ToolRef/spatial_analyst_tools/how_aspect_works.htm. Finally, the aspect was reclassified simplifying the output into their respected cardinal directions (figure 8).

Discussion

In order to understand the actual relationship of the abiotic elements and the forest habitats effected by them, a comparison of the total acre coverage before and after the isolating variables are introduced is essential. In comparing the pre-isolation figures (Figure 9A and 9B) with the post-isolation figures (Figure 10A and 10B), it is apparent that five of the eight forest types demonstrated little isolation from their natural habitat. Specifically, the aforementioned forests include beech, mixed oak, oak-sugar maple, prairie grassland, and freshwater marshes/fens. By calculating percentage of acre coverage loss regarding post-isolation total acreage to the pre-isolation total acreage the greatest loss is less than 2.1%. These results suggest that the five previously mentioned forest types did exist in a habitat with ideal abiotic characteristics for their particular tree species.

Of the five forest types mentioned above, three (beech, mixed oak, and oak-sugar maple) show a preference for shale, siltstone, and mudstone bedrock, with only trace amounts (< 2.8%) found on dolomite, black shale, and sandstone, and zero found on limestone. Freshwater marshes and fens are exclusive to shale, and prairie grasslands are exclusive to dolomite and black shale with less than 10% difference in preference for dolomite.

Bottomland hardwood, elm-ash swamp, and mixed mesophytic forests display much isolation between the pre-isolation and post-isolation results. This isolation is demonstrated by the loss in total acre coverage between the two analyses ranging from 81.3-98.8%. This loss suggests there were other abiotic factors controlling the productive nature of the habitat belonging to these forest types'. Between the two analyses there is also variance in the degree of preference for specific bedrock for each forest type. Bottomland hardwood forests show a preference for either shale or black shale. However, when compared to the pre-isolation results, the post-isolation results show a 7.5% decrease in preference for shale and a 14.2% increase in preference for black shale with trace bedrocks becoming less preferred than in their natural habitat. Elm-ash swamp forests did grow exclusively on shale and sandstone bedrock, with only a 2.6% preference for sandstone over shale, but displays a 13.6% increase in preference for shale in a setting with preferred abiotic characteristics over a natural setting. Mixed mesophytic forests display a preference for shale and siltstone bedrock, with a low preference (< 7%) for black shale and trace preferences for mudstone, dolomite and sandstone. However, post-isolation results display a 21.7% increase in preference for siltstone with a 16.1% decrease in preference towards shale. One observation to note, is the three forest types that display the most variance between the two analyses all prefer a soil pH between 5.5 and 7.5. This suggests soils with this pH range possess some aspect that allow for forest types to occur in areas that possess less than ideal habitat defining characteristics.

From these results, it can be concluded that shale is the preferred bedrock in both natural and ideal habitats for all forest types except for prairie grassland. Dolomite is only preferred by prairie grasslands, with less than a 1% preference by any other forest type. Sandstone is strongly preferred (37.7-51.3%) by elm-ash swamp forest, but is only preferred by other forest types less than 2.7%. Mixed mesophytic forests are the only forest type found on limestone, however, limestone makes up less than 0.01% of the total mixed mesophytic forest bedrock acre coverage.

The analysis performed here is an initial step to encourage future analysis of bedrock as an abiotic component of forest growth. Future studies may include micro scale areas, where more detailed information could be collected and reviewed. Such detailed information should include: a more accurate breakdown of geologic units with their specific chemical and physical characteristics; detailed aspect investigation; micro meteorological events such as early onset of frosting on valley floors; and hydrologic analysis to include micro-ponding. One other analysis essential to the understanding of bedrock effects on forest ecology would be that of soil pH levels and the phenomenon of allowing forests to thrive in habitats that do not possess the ideal abiotic components for their specific tree species.

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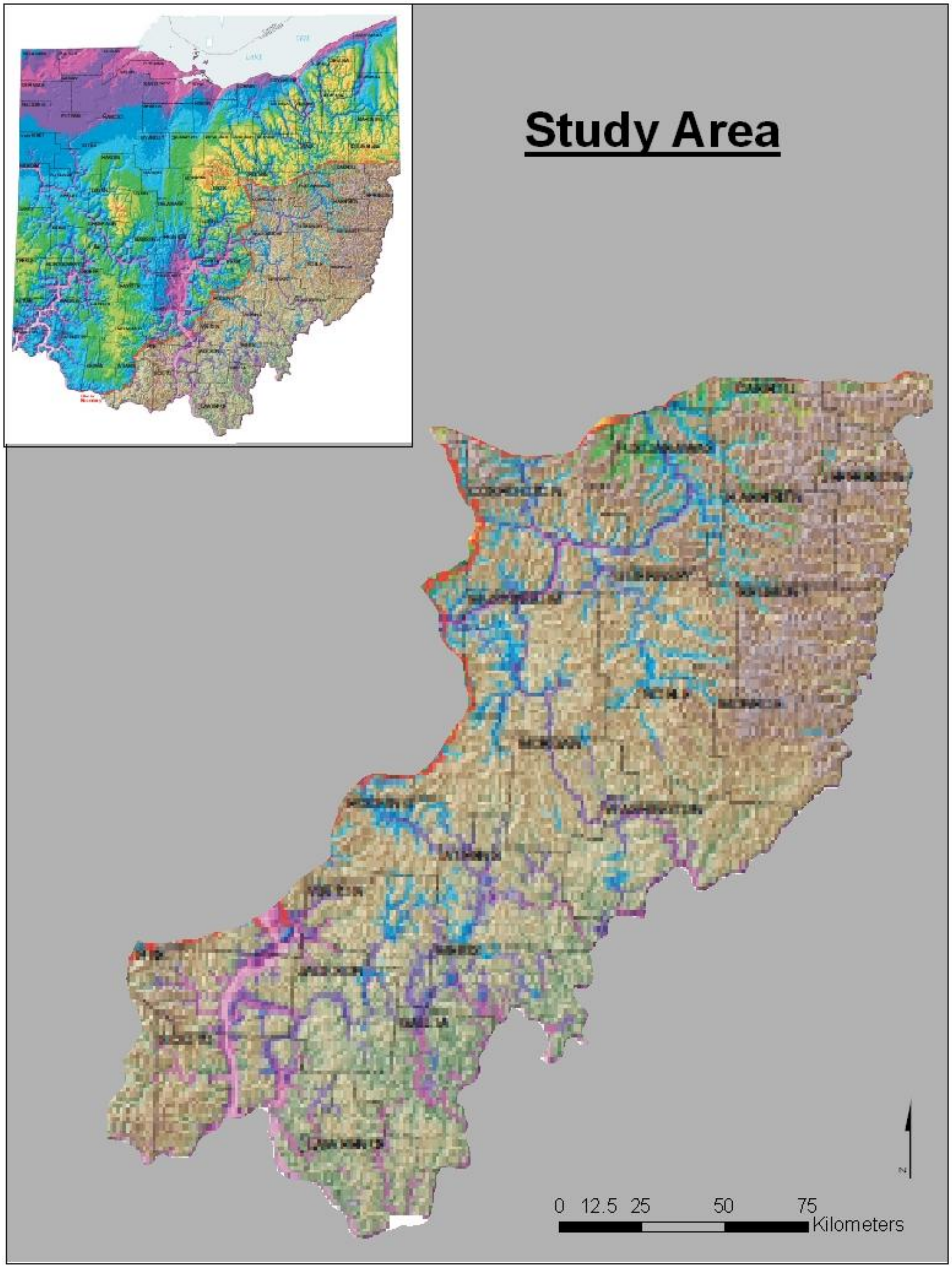


Figure 1. Study Area: The unglaciated Allegheny Plateau

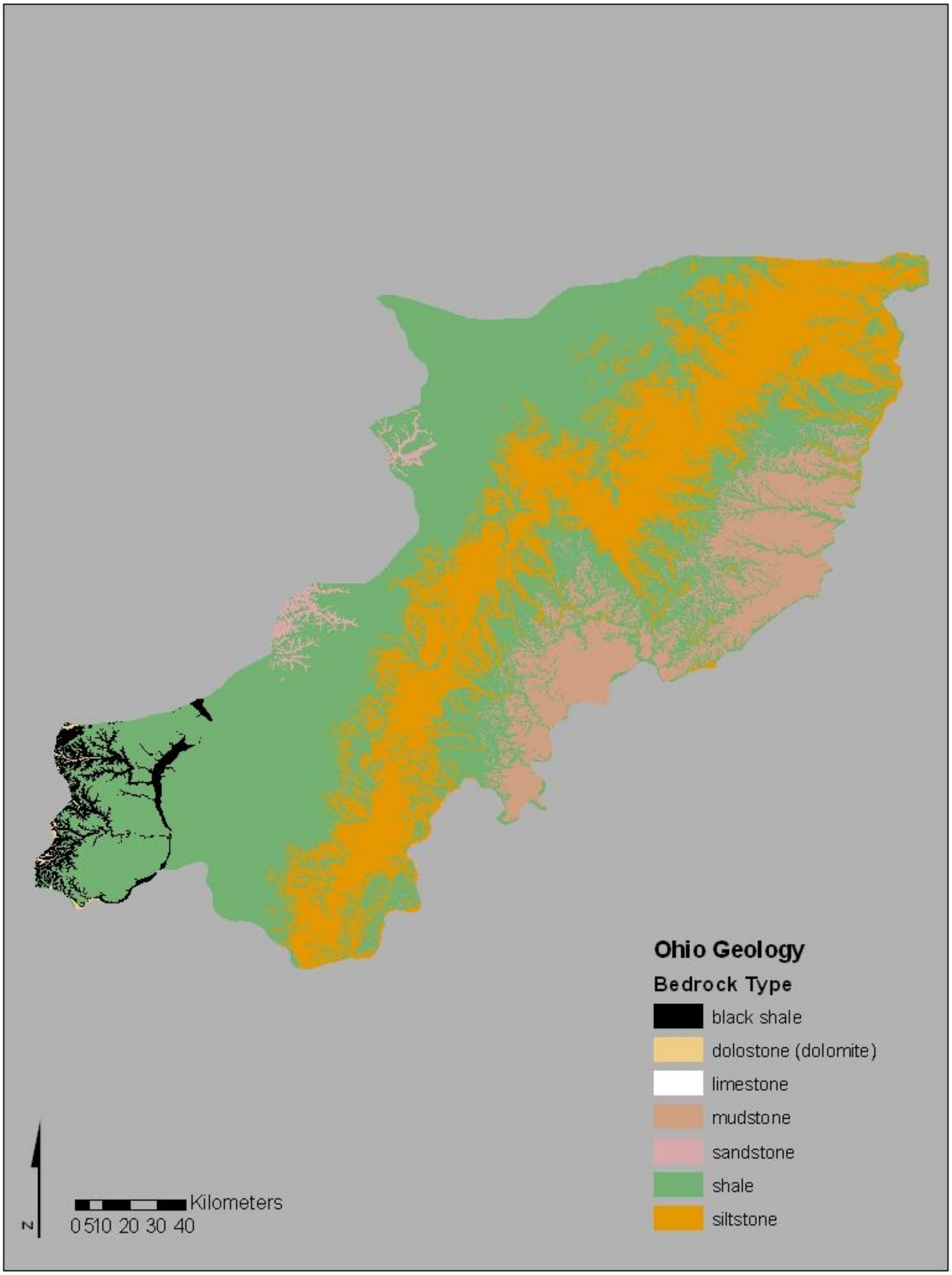


Figure 2. Shapefile representing bedrock geology of the unglaciated Allegheny Plateau

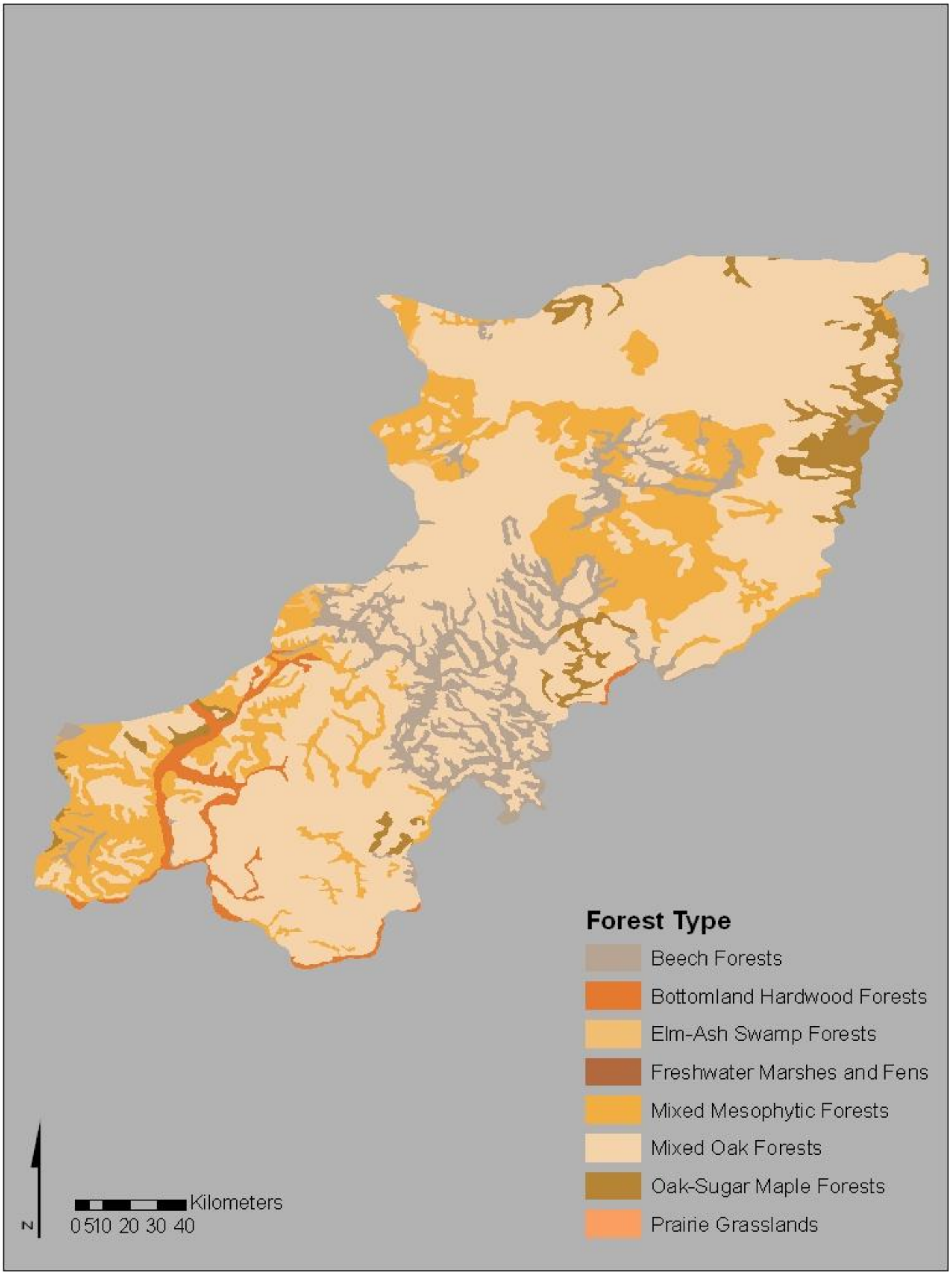
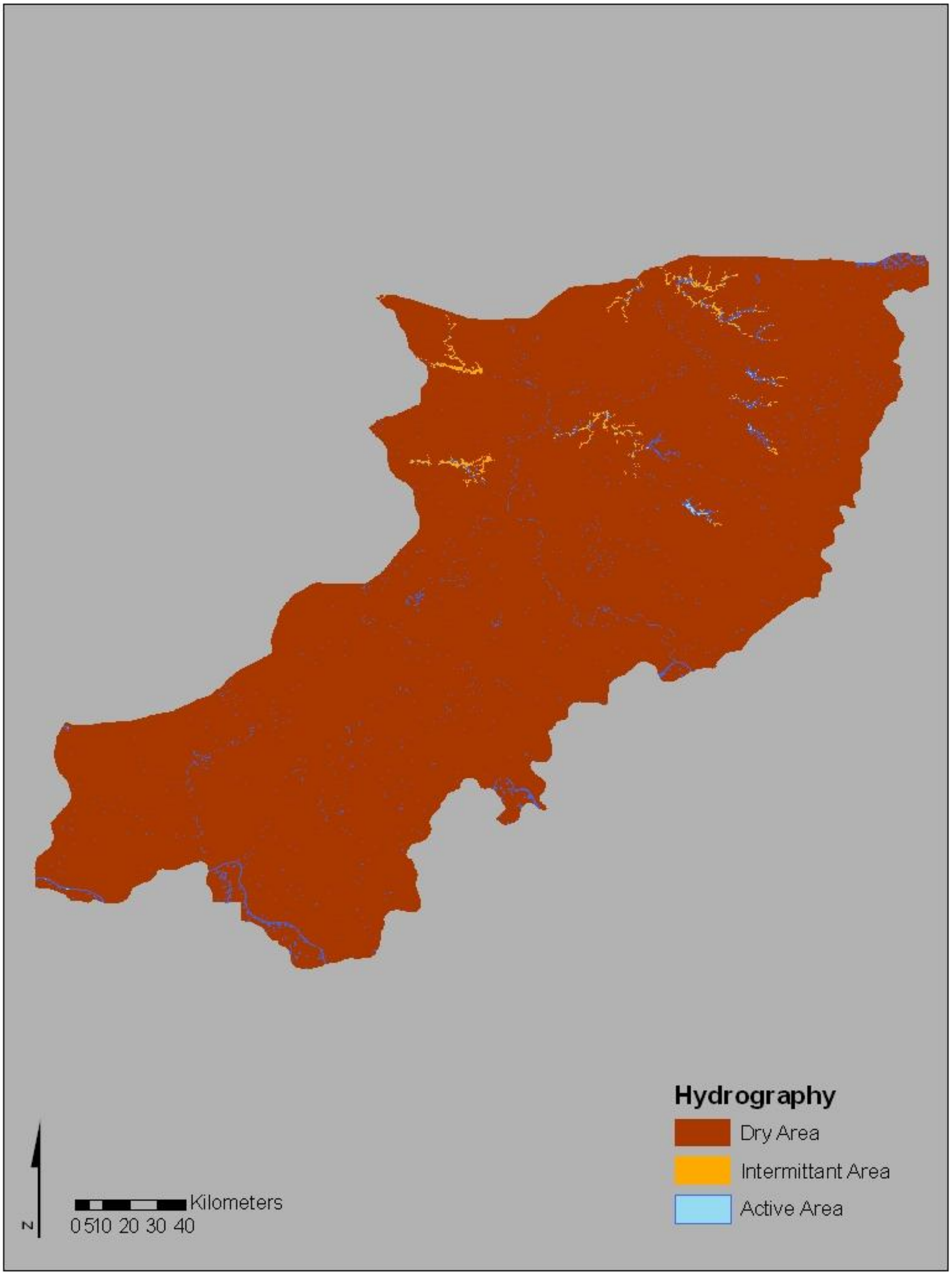


Figure 3. Shapefile of the forest types of the unglaciated Allegheny Plateau

Figure 4. Shapefile representing the hydrology of the unglaciated Allegheny Plateau



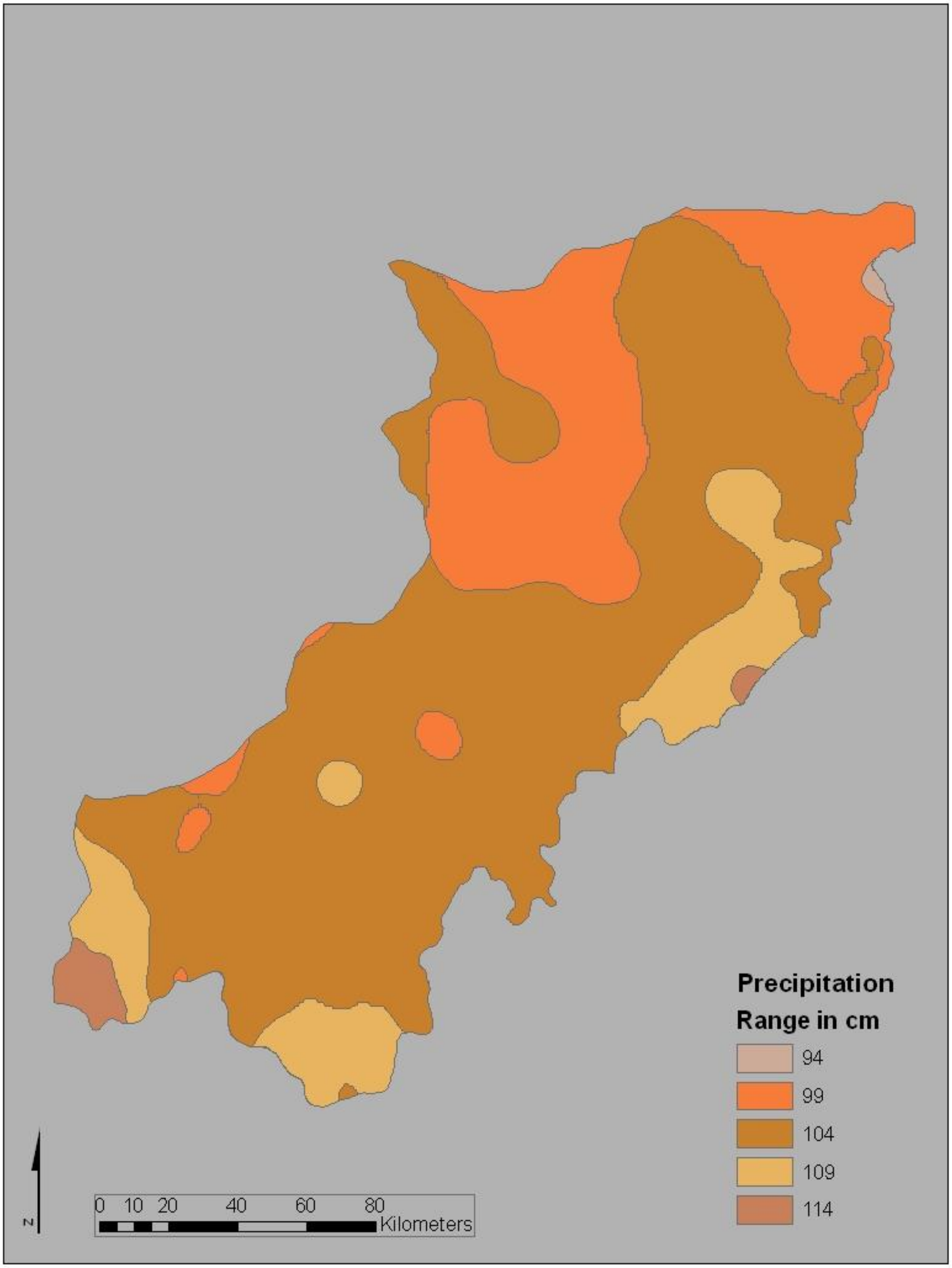


Figure 5. Shapefile of the precipitation rates in inches of the unglaciated Allegheny Plateau

Fig. 22. County map of Ohio showing average number of days between last killing frost in spring and first in autumn computed through 1943. Courtesy Ohio Department of Natural Resources, Division of Water, Bulletin 15.

80

Figure 6: County map displaying the average number of frost-free days (Gordon, 1969)

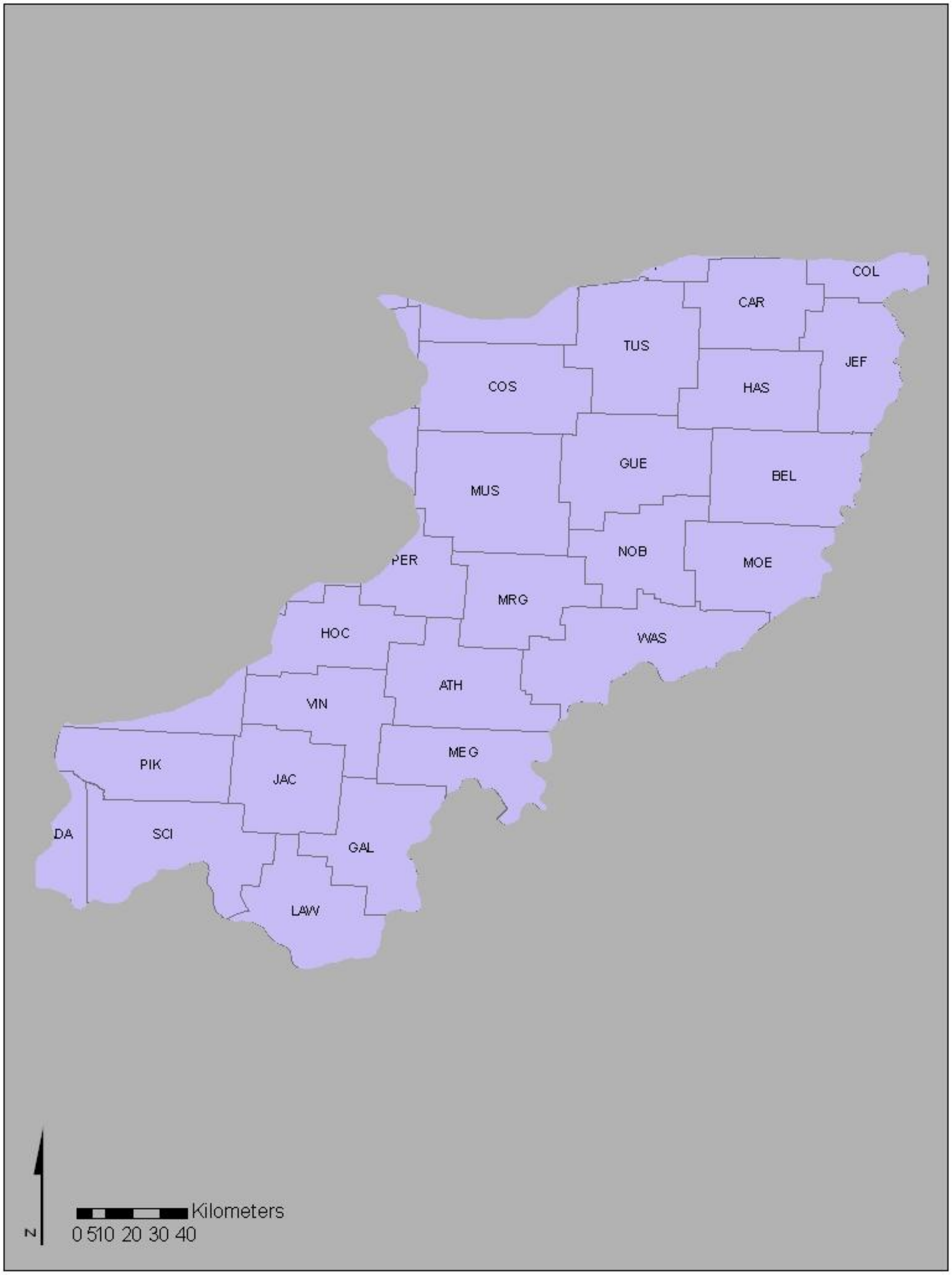


Figure 7. Shapefile of counties in the unglaciated Allegheny Plateau

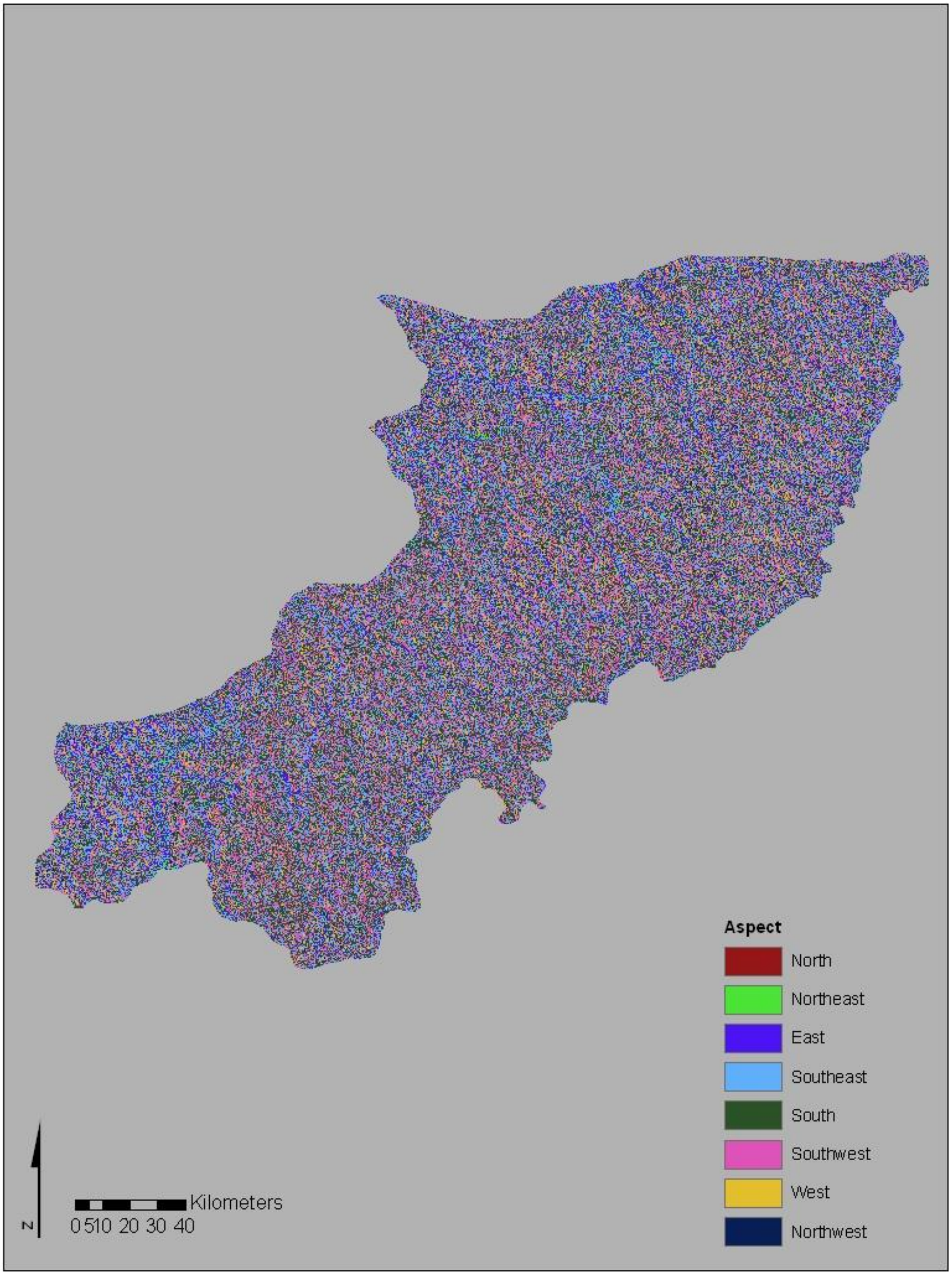


Figure 8. Raster image of aspect analysis based on Ohio Digital Elevation Model

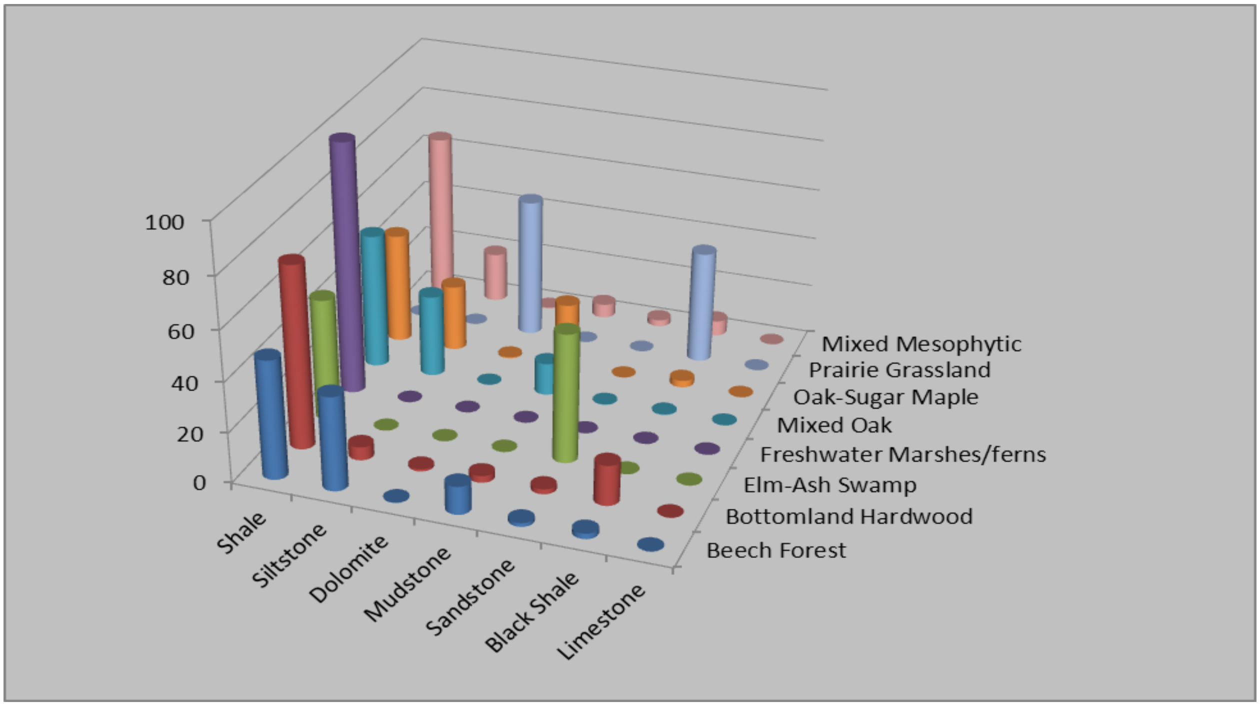


Figure 9A. Pre-isolation percentage of forest type coverage over bedrock type

Forest type	Total Acreage	Shale	%	Siltstone	%	Dolomite	%	Mudstone	%	Sandstone	%	Black Shale	%	Limestone	%
Beech Forest	662354.7	314042.8	47.4	248125.6	37.5	1316.1	0.2	74347.1	11.2	10156.6	1.5	14366.4	2.2	0	0
Bottomland Hardwood	166542	121534.7	73	8814.9	5.3	1482.3	0.9	4574.6	2.7	3394.5	2	26740.9	16.1	0	0
Elm-Ash Swamp	20142.5	9818	48.7	0	0	0	0	0	0	10324.4	51.3	0	0	0	0
Mixed Oak	4646299.6	2501332	53.8	1519932	32.7	198.7	0.004	598906.7	12.9	10498.6	0.2	15423.9	0.3	0	0
Oak-Sugar Maple	300059.1	132061.3	44	79137.3	26.4	1523.8	0.5	79119.2	26.4	0	0	8217.4	2.7	0	0
Mixed Mesophytic	1424480.7	932975.3	65.5	283701.9	19.9	6074.8	0.4	79054.6	5.5	36469.2	2.6	86071.6	6	133.1	0.009
Prairie Grassland	305	0	0	0	0	168.5	55.2	0	0	0	0	136.5	44.8	0	0
Freshwater Marshes/fens	185.4	185.4	100	0	0	0	0	0	0	0	0	0	0	0	0

Figure 9B. Pre-isolation forest type coverage over bedrock type data

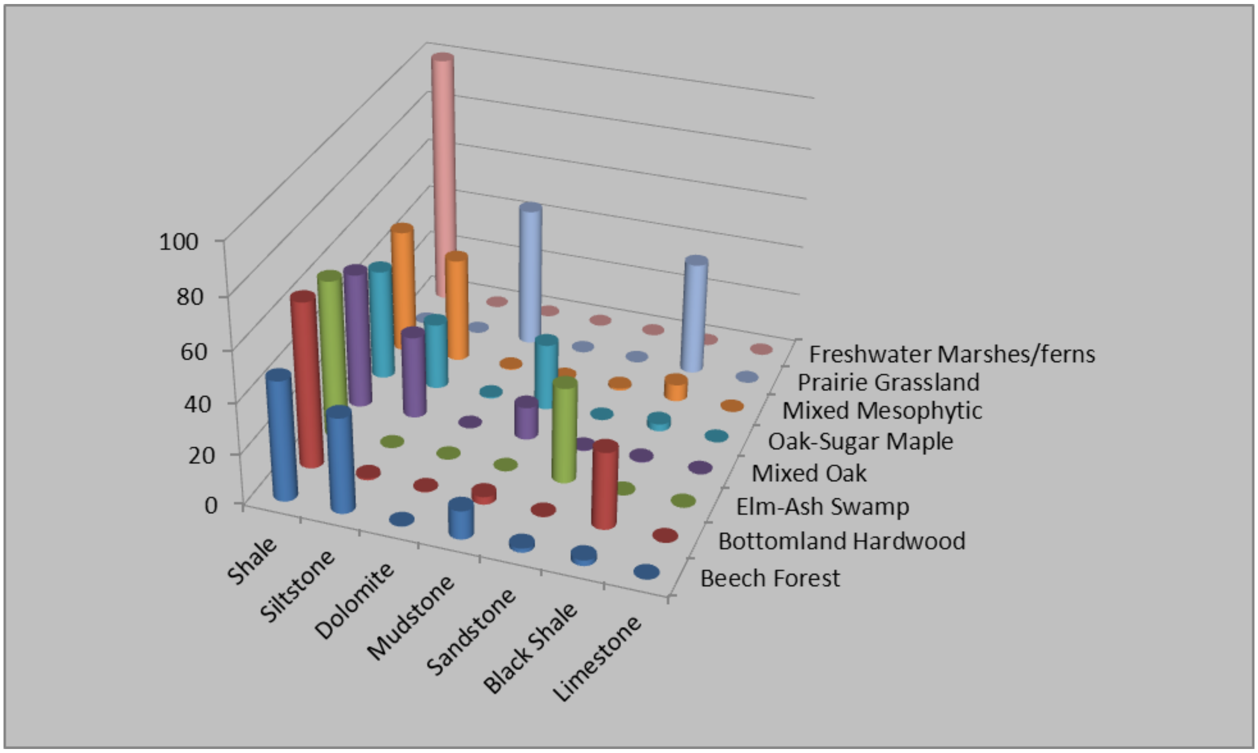


Figure 10A. Post-isolation percentage of forest type coverage over bedrock type

Forest type	Total Acreage	Shale	%	Siltstone	%	Dolomite	%	Mudstone	%	Sandstone	%	Black Shale	%	Limestone	%
Beech Forest	651824.5	308559.9	47.3	244954.7	37.6	934.5	0.1	73068.1	11.2	10135.2	1.6	14172	2.2	0	0
Bottomland Hardwood	3946.7	2587	65.5	26.8	0.7	9.5	0.2	120	3	5.8	0.1	1197.4	30.3	0	0
Elm-Ash Swamp	3760.2	2343.9	62.3	0	0	0	0	0	0	1416.2	37.7	0	0	0	0
Mixed Oak	4550037.2	2444765	53.7	1486412	32.7	164.6	0.003	593498.9	13	10498.6	0.2	14781	0.3	0	0
Oak-Sugar Maple	296731	130530.5	44	78040.7	26.3	1513.7	0.5	78480.5	26.4	0	0	8165.6	2.8	0	0
Mixed Mesophytic	16470.4	8140.2	49.4	6857.7	41.6	71.7	0.4	45.5	0.3	137.8	0.8	1102.3	6.7	0	0
Prairie Grassland	305	0	0	0	0	168.5	55.2	0	0	0	0	136.5	44.8	0	0
Freshwater Marshes/fens	185.4	185.4	100	0	0	0	0	0	0	0	0	0	0	0	0

Figure 10B. Post-isolation forest type coverage over bedrock type data